Generative Green Building Design, Computational Analysis of the Ecological Algorithm

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Abstract. The research deals with the building design aimed at meeting the strict ecological criteria set out by the European legislation of 2020 while using the latest digital technologies of parametric designing in the Grasshopper program. Specifically, we have focused on the architectural design stage. Instead of providing purely technological solution, we preferred to use technology as a part of the architectural concept. The goal was to get closer to the zero energy building concept. Parametrization of the technological, aesthetic and organizational part of the building into a single system as well as parametrization of the surrounding environment was chosen as the tool. The research shows one of the options how to extend the building's information model into the conceptual design stage and how to interconnect data with the environment.

Keywords: Ecology · Digital architecture · Grasshopper

1 Introduction

The classic view of the Smart City issue and contribution to improvement of the urban functioning is considered primarily from the city usage point of view. This is also pointed out by the question of Anthony M. Townsend in his book Smart Cities: *How will a building system talk to each other? How can my phone ask a bus where it is going?* [1]. This is a natural starting point because this information aspect may be applied as a new layer to the existing urban structure. This attitude is further justified by the current fast acceleration of the use of information technologies by the common city residents contrasted by the information passivity of the urban environment.

Another view of the problem is the utilisation of data to optimize flows in the urban environment. Some of the examples already implemented include optimization of public transport or distribution of security forces.

However, the aforementioned strategies fail to solve the issue of designing the essential element of the city, which is the building. In our case, we have restricted the assignment to residential architecture located on the outskirts of the city. In particular, we are considering the territory of deteriorating vineyards above the Bratislava district of Rača. The locality is typical for the Central European context of urban development.

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There is also a difference in similar strategies which are mostly applied to larger agglomerations with more dynamic growth of the urban structure.

When searching for the limits within the building's ecological aspect, we were trying to suppress the purely technological solutions as much as possible and to prefer using technologies as a part of the architectural concept. The solution was directed to simple technologies, already available, used in an innovative way. The goal was to get closer to the zero energy building, the definition of which clarifies our energy goals. *A Zero Energy Building (ZEB) shall mean a building producing (at least) as much energy as it needs for its operation from renewable sources throughout the year. Therefore, the need of primary energy is fully covered by the energy obtained from the environment or from renewable sources in/on/at the building. The coverage is evaluated in annual balance* [2].

Ideological architectural background of sustainable architecture contains social and aesthetic parameters as well as the parameter of environmental quality. This concept was further developed by prof. Keppl in his work Ecological Algorithm of Designing. He defines this issue as follows: *Algorithm is based on the principle of designing in accordance with the environment (idea of bio-climatic architecture - see Ecological architecture) and utilisation of the characteristics of the environment, locality and natural forces, especially the sun and wind, for the benefit of functioning of the object designed* [3].

2 Parametrization of Architecture

The aforementioned starting points form a diverse milieu of relationships and information which has to be considered when designing a building. Compared to the standard architectural practice, there is a number of new factors which shall be considered in designing. Upon reaching a certain amount of data, the human factor loses its ability to meaningfully analyse and interpret information. Utilisation of digital technologies is inevitable.

The procedure required quantification of individual components creating the architectural diagram, inscription thereof into a unified data format, definition of their relations and enabling three-dimensional interpretation of data in architectural form. The whole system has to be interactive (recursive), in order to enable redefinition of input data and thus optimization of the resulting form at any stage.

Since beauty was one of the parameters required, in other words, aesthetic appropriateness of forms in relation to the surrounding environment, we have chosen the Rhinoceros Grasshopper[1] modelling program add-on as a tool. This is a graphical algorithm editor which enables to create generative algorithms. The greatest advantage is the integration into architectural modelling environment. Thus, the outputs are dynamically interpreted in 3d objects which may be further interpreted in perspective imaging. This is a form of graphic programming language which enables standard calculations and thereby integration of various data forms.

[1] http://www.grasshopper3d.com/.

Aesthetic Parameter. The Parameter is based on the analysis of the concept of beauty and its definitions. The basis was the analysis of compositions of implemented projects on photographs in a particular environment. Selection was based on known and positively perceived built architectures in similar natural environment. In terms of composition, the mutual ratio of area elements was evaluated: architecture, environment in front of the object, environment behind the object and the sky. The goal was to quantify the ratio of individual elements which creates an aesthetically satisfactory view of architecture in natural environment.

The analyses resulted in a proposal of several material structures with the same volume which are subsequently evaluated in terms of composition and area in the environment, always in three identical points: panoramic view, oncoming view, point in the environment between the matters. All of the views are composed so that the observed object, architecture in our case, is compositionally fitted according to the golden section principle in a frame which has the 16:9 ratio. The process is automated by the script which generates different types of architectural forms in the modelling environment, meeting the given criteria, including evaluation of their aesthetic quality (Figs. 1, 2 and 3).

Fig. 1. Example of architectonic style in countryside: “Monument of Beauty”, reproduction of (Ondrej Kövér 2015) original building: Marte. Marte Architects Mountain Cabin, Laternser Valley, Austria (2011).

The Energy Parameter. The energy concept is based on the effort to make the most of the morphology and genius loci of the environment as the potential source for producing energy needed to cover the building’s energy consumption.

Energy consumed in the particular residential house with 40 residents may be divided in three units. Energy needed for the domestic hot water (DHW), energy needed for heating and energy needed for the running o household devices. The best way of energy production was searched for these three separate units. This resulted in a complex formula working on the basis of the object’s volume and floor area (Fig. 4).

Energy needed for the domestic hot water was acquired by using solar panels. According to the calculations above, 13544 kWh/year is consumed for DHW. According to the research by Krippelová and Peráčková [4], annual consumption of hot water is 16.76 m^3 per resident. Consumption of hot water during the year, week and even day is a very fluctuating value. Therefore, it is necessary to have the system dimensioned for the maximum possible water consumption, to be able to cover the water consumption at its maximum value. According to the research, the highest water consumption is on a Sunday, in particular 52 l per person. Considering the number of residents, the reservoir with capacity of 3120 l is needed (consumption × residents × 1.5). According to the formula for preliminary draft of the solar collector surface (number of persons × 1.5), [5] the preliminary surface of collectors needed is 60 m^2. Considering the values calculated, we recommend to use 6 times the system for water heating with the surface of 8.73 m^2, reservoir capacity of 500 l, 24 tube collectors (Fig. 5).

The second unit is the energy needed for heating of the building itself. Energy for the building heating forms 33 % (15962 kWh/year) of total energy consumed. When the floor height calculated is 3 m, the total heated volume is 3,224 m^3. The boiler

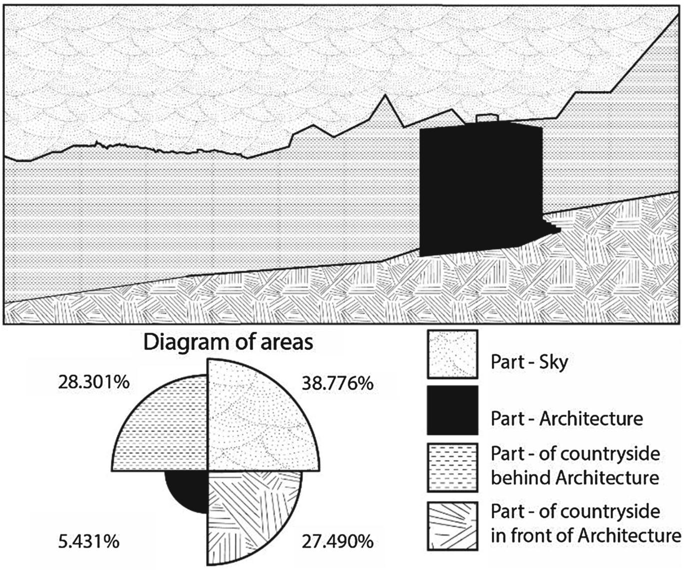

Fig. 2. Evaluation of composition, frame 16:9 (Ondrej Kövér 2015)

output is calculated empirically as the volume of the object in m3 x estimated heat output (20 W/m^3, new development, insulated) [6]. These values require a boiler with output of 64 kW. We propose a pellet boiler, with the efficiency factor of 0.92. Obtaining of the raw material for the boiler from the vineyard was also considered, whereby both the transportation cost and the carbon footprint of the fuel used would be decreased. By using the software support, we were able to simulate the vineyard as the

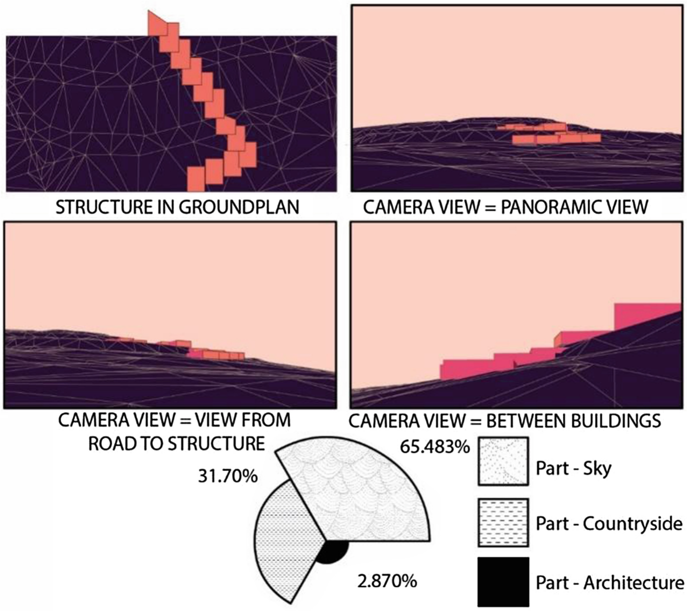

Fig. 3. Generating different types of structure and analysing the composition. Frame 16:9 (Ondrej Kövér 2015).

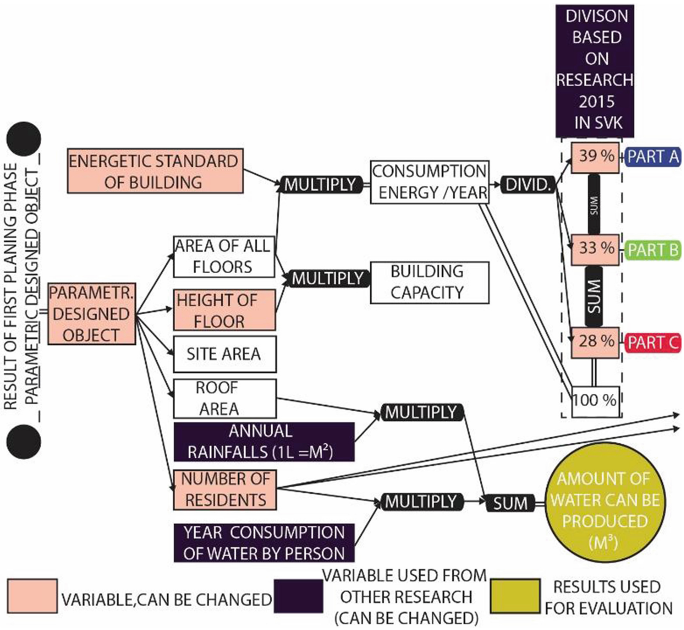

Fig. 4. Interpretation of technical part of the Grasshopper diagram (Ondrej Kövér 2015).

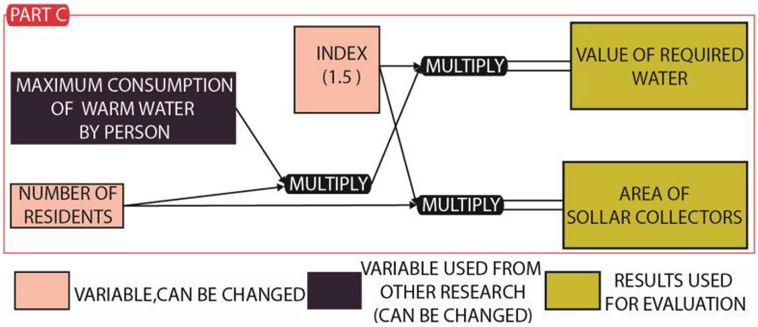

Fig. 5. Part C Energy required for water heating 28 % from all energy required (Ondrej Kövér 2015).

source of different types of fuel, as each material has a different heat value per kilogram. At the same time, the relevant area of vineyard needed for obtaining sufficient volume of fuel for a year was simulated. For example, with the heat value of wooden pallets being 5 kWh/kg, at the boiler effectiveness of 0.92, we would need 3,470 kg of pellets to cover the consumption. Assuming that from 1 m^2 of vineyard, we are able to obtain 0.5 kg of wooden pellets, the vineyard area needed would be 6940 m^2 (Fig. 6).

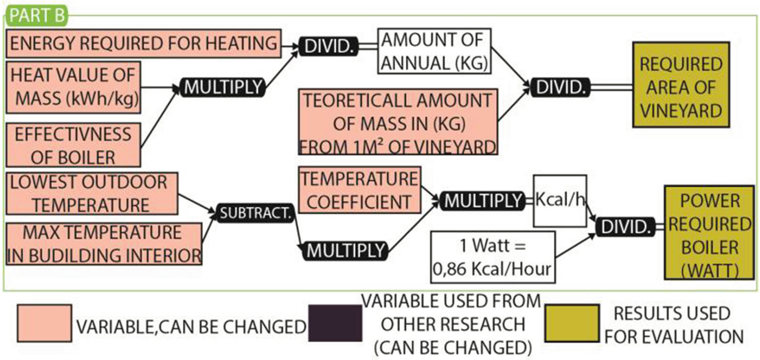

Fig. 6. Part B Energy required for heating 33 % from all required energy (Ondrej Kövér 2015).

The last unit is the energy needed to cover the running of household devices. 39 % of total energy (18865 kWh/year) falls upon household devices. Energy needed to cover devices will be obtained from photovoltaic cells. This calculation was facilitated by the GIS data prepared for the given locality. If we were to cover the full consumption of electric power under the formula (solar panel surface × solar panel output in WP × surface of a single panel × amount of sun energy per 1 m^2 per year * 0.7 loss factor) [7], we would need 290 m^2 of photovoltaic cells. The issue is the uneven power input considering the amount of sunlight both over the day and the year. In case of surpluses,

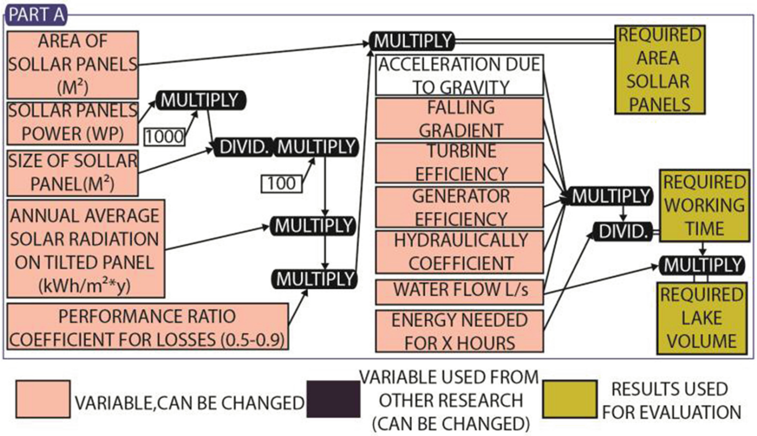

Fig. 7. Part A Energy required for household devices 39 % from all required energy (Ondrej Kövér 2015)

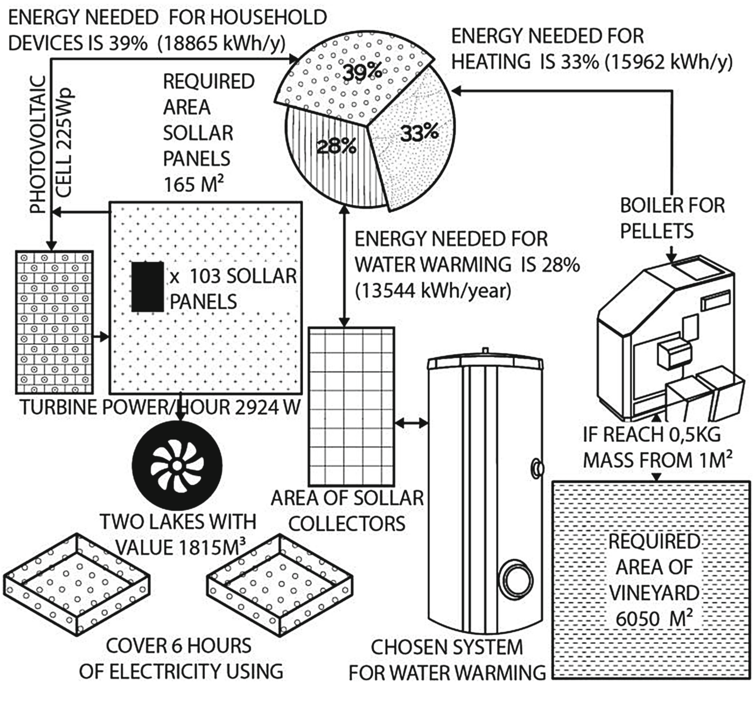

Fig. 8. Diagram of separation and functioning of the energy concept (for 1,075 m^2 floor area is the energy consumption of 48 372 kWh) Division based on research of standard Slovak housing energy consumption. (Ondrej Kövér 2015).

we can store such unsteadiness into water energy. With respect to the terrain morphology, we decided to build three lakes on three terraces. During the day, in case of surpluses of electric power, water will be pumped from the lowest lake to the highest one. During the lack of electric power obtained from photovoltaic panels, this water is released through piping to the lowest lake and spins the micro-turbine, whereby the needed amount of electricity is acquired. Thanks to the software, it is possible to determine the size of the lake considering the amount of hours covered by this source. For example, we need 10,767 W of energy to cover 5 h, under gravity acceleration of 9.81 and difference in lake elevation of 14.197 m, efficiency of the micro-turbine 0.7 and efficiency of the generator 0.8, we will get the water flow needed of 50 litres per second and the resulting output 2,924 kW per hour. In order to use and cover the consumption of 5 h, two lakes with area of 18 m^2 and depth of 3 m were needed (Fig. 7).

This energy concept of collection lakes also create a new qualitative category of the environment and architecture at the same time. When designing the technology, we also need to take into account how the technology will be reflected in the form (façade) of the building itself (Fig. 8).

Fig. 9. Final architecture of generated apartment house. (Ondrej Kövér 2015).

3 Generated Architecture - Conclusion

Technological solutions such as insulation and building equipment are a part of the building solutions. At present, the research in building technologies is very common and constantly brings us new and better solutions. In our research, we were trying to support architectural solutions of the issue relating to the shape of the building, its orientation and interaction with its immediate surroundings.

The building becomes an organism, is not separated but communicates with the surrounding, which does not only consist of other buildings but the surrounding cultural landscape as well. In order to achieve that the building's communication was not only restricted to the metaphoric level, it was necessary to create a common language whereby the individual parts of the architectural and construction process could communicate with one another. This language consists in parametrization of both technological and architectural parts of the structure as well as parametrization of the environment the architecture is being incorporated in.

At the time, digital architecture has tools to perform such parametrization during early stages of the architectural concept. These data may be further transferred to the project in the BIM environment and subsequently, such information may be integrated into the broader information relations within the city. Buildings communicate not only about their output and production of energy but about their form as well. There is an option to evaluate mutual urban interactions of the buildings, starting with the parking spaces up to the entitlement for sun of the future buildings. The research shows one of the options how to extend the building's information model into the conceptual design stage and how to interconnect data with the environment (Fig. 9).

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